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Constraints on Secondary Eclipse Probabilities of Long-Period Exoplanets from Orbital Elements

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Abstract. Long-period transiting exoplanets provide an opportunity to study the mass-radius relation and internal structure of extrasolar planets. Their studies grant insights into planetary evolution akin to the solar system planets, which, in contrast to hot Jupiters, are not constantly exposed to the intense radiation of their parent stars. Observations of secondary eclipses allow investigations of exoplanet temperatures and large-scale exo-atmospheric properties. In this short paper, we elaborate on, and calculate, probabilities of secondary eclipses for given orbital parameters, both in the presence and absence of detected primary transits, and tabulate these values for the forty planets with the highest primary transit probabilities.

1. Introduction

Secondary eclipses of exoplanets provide unique insight into their astrophysical properties such as surface temperatures, atmospheric properties, and efficiency of energy redistribution. In Kane & von Braun (2008, 2009), we demonstrate that the probability of detecting transits or eclipses among known radial velocity (RV) planets is sensitively dependent on the values of orbital eccentricity e and argument of periastron ω, with some combinations of e and ω making transit/eclipse searches among long-period planets viable. Though it is feasible to detect planetary eclipses from space (e.g., Laughlin et al. 2009) and even from the ground (e.g., Sing & López-Morales 2009), the difference in signal-to-noise ratio between transits and eclipses makes detections of the former much more straightforward. In this paper, we calculate the probability of planetary eclipses with or without the knowledge of the existence of a primary transit.

2. Planetary Eclipse Probabilities

The *a priori* geometric eclipse probability of an extrasolar planet, P_e, is

$$P_e = \frac{(R_{planet} + R_\star)(1 + e\cos(3\pi/2 - \omega))}{a(1-e^2)}, \quad (1)$$

where R_{planet} and $R_\star$ are planetary and stellar radii, respectively (Kane & von Braun 2009). P_e is highest for $\omega = 3\pi/2$.

The presence of an observed transit imposes a lower limit to the orbital inclination angle i, which, using equations 8–11 in Kane & von Braun (2009), provides the following (conditional) lower limit of P_e:

$$P'_e \geq \frac{(R_\star + R_{planet})}{(R_\star - R_{planet})} \frac{(1 - e\cos\omega)}{(1 + e\cos\omega)}. \tag{2}$$

3. Discussion

Figure 1 plots the *a priori* values (open circles) and conditional lower limits (crosses) of P_e for 203 planets as functions of e and ω values tabulated in Butler (2006). The *left* panel clearly shows that, for low values of e, the existence of a transit practically guarantees an observable eclipse, whereas for higher eccentricities, this is not the case due to the correspondingly weaker constraint on inclination angle imposed by an existing transit (cf. Equation 8 in Kane & von Braun 2009). The *right* panel demonstrates that, for $\omega \sim 3\pi/2$, a detected transit ensures the existence of an observable eclipse , whereas for $\omega \sim \pi/2$, this constraint is much weaker (cf. Figure 1 in Kane & von Braun 2009). Thus, the presence of a planetary transit greatly affects the likelihood of existence of a secondary eclipse. Both the *a priori* value and the conditional lower limit of P_e remain sensitively dependent on the combination of e and ω.

Table 1 shows the forty extrasolar planets with the (currently) highest transit probabilities, their orbital elements P, e, and ω, and the explicit values for eclipse probabilities (P_e: *a priori* value; P'_e: conditional lower limit). For instance, HD 118203 b has $P_e = 7.05\%$, but *if a primary transit is observed* ($P_t = 9.11\%$), then the existence of a secondary eclipse is almost certain ($P'_e \geq 94.65\%$). See Table 1 in Kane & von Braun (2009) for the equivalent inverse case of $P_t = f(P_e)$.

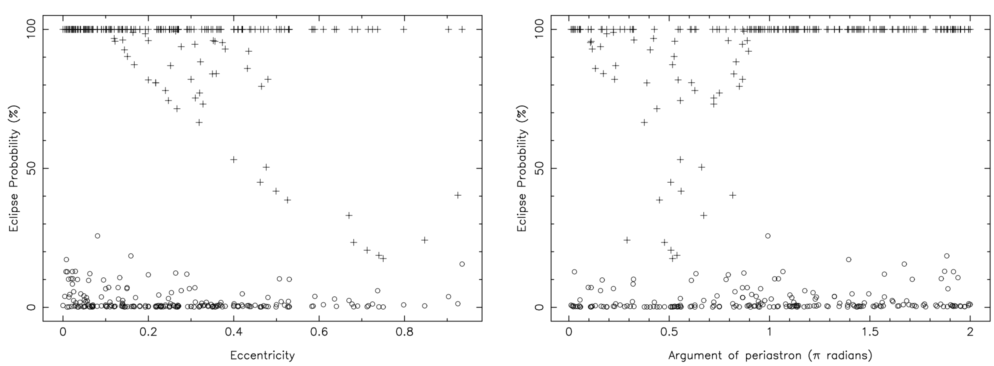

Figure 1. The *a priori* values of P_e (Equation 1; open circles) and conditional lower limits of P_e (Equation 2; crosses) for 203 planets from the Butler (2006) catalog, plotted as a function of e and ω. For purpose of comparison, we assume solar and Jupiter masses and radii for all systems.

Table 1. P_t, *a priori* P_e, and conditional (revised) P'_e for the 40 exoplanets from Butler (2006) with highest P_t values. See §3.

Planet	P (days)	e	ω(deg)	P_t (%)	P_e (%)	P'_e (%)
HD 41004 B b	1.33	0.08	178.50	25.81	25.70	100.00
HD 86081 b	2.14	0.01	251.00	16.93	17.19	100.00
GJ 436 b	2.64	0.16	339.00	16.50	18.50	100.00
55 Cnc e	2.80	0.26	157.00	15.17	12.33	99.36
GJ 674 b	4.69	0.20	143.00	14.93	11.72	95.96
HD 46375 b	3.02	0.06	114.00	13.58	12.11	100.00
HD 187123 b	3.10	0.01	5.03	12.81	12.78	100.00
HD 83443 b	2.99	0.01	345.00	12.77	12.82	100.00
HD 179949 b	3.09	0.02	192.00	12.74	12.86	100.00
HD 73256 b	2.55	0.03	337.00	12.66	12.95	100.00
HD 102195 b	4.12	0.06	109.90	10.85	9.69	100.00
HD 76700 b	3.97	0.09	29.90	10.82	9.84	100.00
HD 75289 b	3.51	0.03	141.00	10.47	10.03	100.00
51 Peg b	4.23	0.01	58.00	10.35	10.12	100.00
τ Boo b	3.31	0.02	188.00	10.21	10.27	100.00
HD 88133 b	3.42	0.13	349.00	10.16	10.68	100.00
BD -10 3166 b	3.49	0.02	334.00	10.15	10.32	100.00
HAT-P-2 b	5.63	0.51	184.60	9.44	10.24	100.00
HD 17156 b	21.20	0.67	121.00	9.14	2.47	33.05
HD 118203 b	6.13	0.31	155.70	9.11	7.05	94.65
υ And d	4.62	0.02	57.60	8.69	8.38	100.00
HD 68988 b	6.28	0.15	40.00	8.20	6.76	100.00
HIP 14810 b	6.67	0.15	160.00	7.86	7.10	100.00
HD 162020 b	8.43	0.28	28.40	7.84	6.02	93.77
HD 217107 b	7.13	0.13	20.00	7.76	7.11	100.00
HD 168746 b	6.40	0.11	17.40	7.63	7.16	100.00
HD 185269 b	6.84	0.30	172.00	7.30	6.72	100.00
HD 49674 b	4.94	0.29	283.00	6.68	11.94	100.00
HD 69830 b	8.67	0.10	340.00	6.24	6.68	100.00
HD 130322 b	10.71	0.03	149.00	5.76	5.62	100.00
HD 33283 b	18.18	0.48	155.80	5.31	3.56	82.03
HD 38529 b	14.31	0.25	100.00	5.21	3.17	74.40
HD 55 Cnc b	14.65	0.02	164.00	4.67	4.63	100.00
HD 13445 b	15.76	0.04	269.00	4.47	4.85	100.00
HD 27894 b	17.99	0.05	132.90	4.43	4.12	100.00
HD 108147 b	10.90	0.53	308.00	4.14	10.09	100.00
HD 6434 b	22.00	0.17	156.00	4.02	3.50	100.00
HD 190360 c	17.11	0.00	168.00	3.94	3.93	100.00
HD 20782 b	585.86	0.93	147.00	3.92	1.29	40.33
GJ 876 c	30.34	0.22	198.30	3.85	4.44	100.00
HD 99492 b	17.04	0.25	219.00	3.83	5.29	100.00

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